PEDESTRIAN TRAVEL-TIME MAPS FOR HOMER, ALASKA:
An anisotropic model to support tsunami evacuation planning

by

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ABSTRACT

Tsunami-induced pedestrian evacuation for the community of Homer is evaluated using an anisotropic modeling approach developed by the U.S. Geological Survey. The method is based on path-distance algorithms and accounts for variations in land cover and directionality in the slope of terrain. We model evacuation of pedestrians to the tsunami hazard zone boundary and to predetermined assembly areas. The pedestrian travel-time maps are computed for two cases: for travel across all viable terrain or by roads only. Results presented here are intended to provide guidance to local emergency management agencies in tsunami inundation assessment, evacuation planning, and public education to mitigate future tsunami hazards.

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INTRODUCTION

Subduction of the Pacific plate under the North American plate has resulted in numerous great earthquakes and has the highest potential to generate tsunamis in Alaska (Dunbar and Weaver, 2008). The Alaska–Aleutian subduction zone (figure 1), the fault formed by the Pacific–North American plate interface, is the most seismically active tsunamigenic fault zone in the U.S. Refer to Suleimani and others (2005) for an overview of the tsunami hazard in the Homer area.

On March 27, 1964, the Prince William Sound area of Alaska was struck by the largest earthquake ever recorded in North America. This M_w 9.2 megathrust earthquake generated the most destructive tsunami in Alaska history. The city of Homer experienced the local landslide-generated waves as well as the tectonic tsunami (Waller, 1966). The destructive power of the tectonic tsunamis was limited because the largest waves arrived at low tide (Waller, 1966). An in-depth analysis of the tsunami hazard in Homer and estimation of the tsunami hazard zone in the community was conducted by Suleimani and others (2005). According to the tsunami modeling results, people who are on the Homer Spit—a narrow glacial feature extending approximately 7.2 km (4.47 mi) from the town of Homer into Kachemak Bay—may face a challenge to evacuate due to long walking distances to safety.

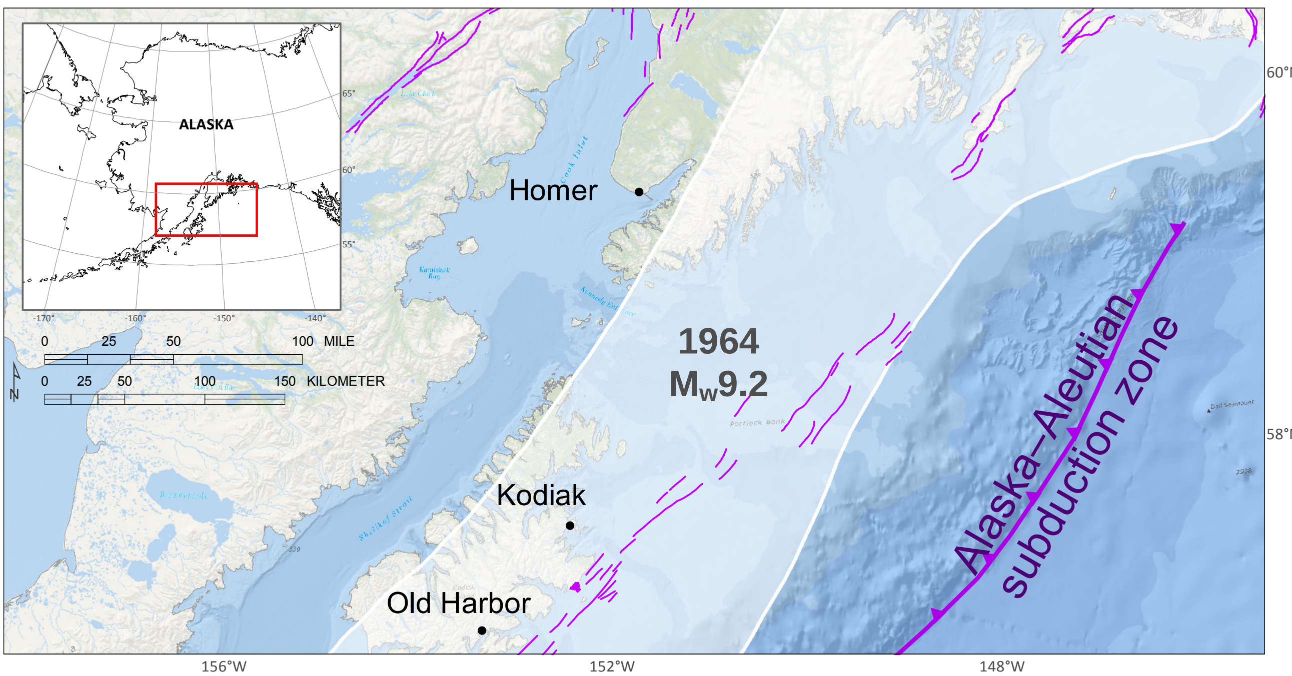


Figure 1. Map of south-central Alaska, identifying major active faults (dark purple lines) and the rupture zone of the 1964 earthquakes (light shaded area).

In this report, we employ the pedestrian evacuation modeling tools developed by the U.S. Geological Survey (USGS) (Wood and Schmidtlein, 2012, 2013; Jones and others, 2014) to provide guidance to emergency managers and community planners in assessing the amount of time required for people to evacuate out of the tsunami-hazard zone. An overview of the pedestrian evacuation modeling tools, required datasets, and the step-by-step procedure used is provided in Macpherson and others (2017).

The maps of pedestrian travel time can help identify areas in Homer on which to focus evacuation training and tsunami education. The resulting travel-time maps can also be used to examine the potential benefits of vertical evacuation structures, which are buildings or berms designed to provide a local high ground in low-lying areas of the hazard zone.

COMMUNITY PROFILE

The community of Homer (figure 2) (59.6431°N, 151.5258°W), population 5,310 (U.S. Census Bureau estimate for 2013), is located on the Kenai Peninsula, along the southeastern part of Cook Inlet, in Kachemak Bay, about 358 km (222.3 mi) southwest of Anchorage.

Figure 2. Looking north along the Homer Spit toward Homer, Alaska.

The community of Homer has developed a significant visitor industry. Thousands of people come to sightsee, fish, hike, and view wildlife, mostly during the summer months. The Homer small boat harbor is home to more than 700 charter and commercial boat operations year-round, growing to 1,500 in the summer months. Local, state, and federal government offices are located in downtown Homer. The commercial and industrial center of the community is the Homer Spit. It enjoys heavy summer recreational use and is especially vulnerable to large sea waves. Severe storms accompanied by high water levels and waves have occasionally overtopped the roadway on the Homer Spit, causing the road to be closed (Suleimani and others, 2005).

TSUNAMI HAZARD

Tsunami hazard assessment for Homer was performed by numerically modeling hypothetical scenarios (Suleimani and others, 2005). Worst-case hypothetical scenarios were defined by analyzing the tsunami hazards along the Alaska–Aleutian subduction zone. The worst-case scenarios for Homer are thought to be a hypothetical repeat of the 1964 earthquake and a hypothetical rupture of the Border Ranges fault. According to Suleimani and others (2005), the maximum predicted wave near Homer could reach 5 m (16.4 ft) and could cause damage and flooding of the spit. The numerical simulations predict that the first wave could arrive as quickly as 15 minutes after the earthquake, whereas the highest wave might arrive 30 minutes after the earthquake. Significant wave activity could continue for at least 3 hours after the earthquake. We note that the tsunami hazard analysis has advanced considerably since 2005 and some additional tsunamigenic earthquake scenarios will be considered for the comprehensive tsunami hazard assessment in Homer.

The estimated inundation limit modeled by Suleimani and others (2005) in Homer is shown in figure 3. According to the modeled tsunami scenarios only low-lying areas of the Homer Spit might be inundated by potential tsunamis. However, the referenced modeling study did not take into the account local subsidence resulting from consolidation of the ground material composing the spit area. For example, after the 1964 event, an average subsidence along the spit was 5.3 ft (1.62 m) (Waller, 1966), whereas tectonic subsidence accounted only for about 2 ft (0.61 m) of the total subsidence along the entire spit. The area of greatest subsidence of about 10 ft (3 m) was at the end of the spit where a soil pile was formed by excavation of the harbor. Therefore, much larger areas of the spit might be flooded by the potential tsunamis. Much of the economic activity, tourism infrastructure, and some residential houses thus potentially lie within the hazard zone; harbors, ports, and canning facilities are all situated on the spit.

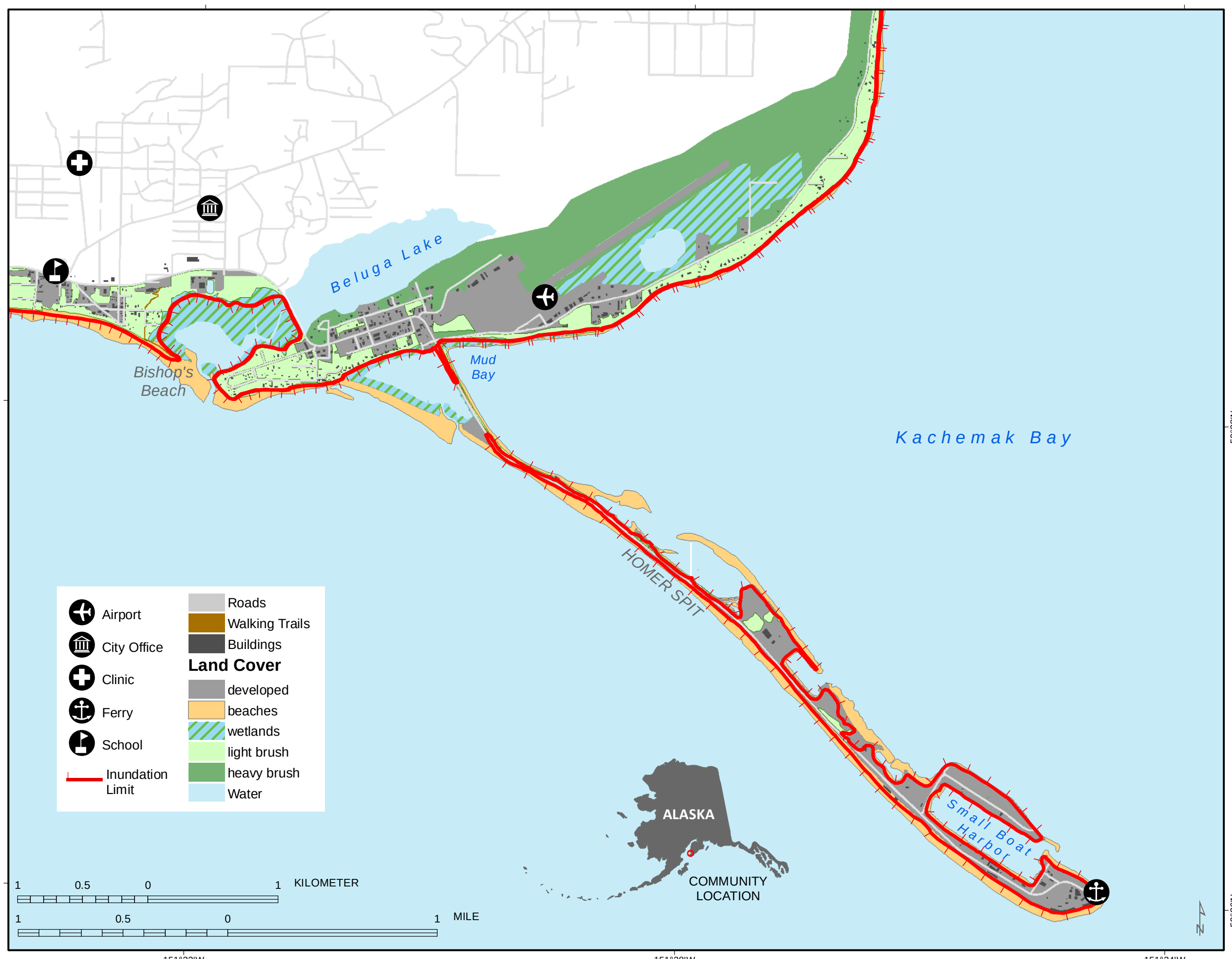


Figure 3. Map of Homer, depicting key facilities, land cover and the inundation limit (red line with hatch marks toward the potential inundation zone) from Suleimani and others (2005).

The hydrodynamic model used to calculate propagation and runup of tsunami waves is a nonlinear, velocity-formulated, shallow-water model. Refer to Suleimani and others (2005) for further details regarding the numerical scheme that was used, as well as for a discussion of uncertainties in the modeled tsunami hazard zone. Note that the accuracy of modeling results is affected by many factors, including suitability of the earthquake source model, accuracy of the bathymetric and topographic data, and the adequacy of the numerical model in representing the generation, propagation, and runup of tsunamis.

PEDESTRIAN EVACUATION MODELING

Pedestrian evacuation modeling and prediction of population vulnerability to tsunami hazards were successfully applied to coastal communities in Alaska by Wood and Peters (2015). Also refer to Wood and Schmidtlein (2012, 2013) for an overview and limitations of the anisotropic, least-cost distance (LCD) approach to modeling pedestrian evacuation. We stress that the LCD focuses on the evacuation landscape, using characteristics such as elevation, slope, and land cover to calculate the most efficient path to safety. Therefore, computed travel times are based on optimal routes and actual travel times may be greater, depending on individual route choice and environmental conditions during an evacuation.

Recently, Jones and others (2014) developed the Pedestrian Evacuation Analyst Extension (PEAE) for ArcGIS, which facilitates development of pedestrian travel-time maps. A brief overview of the PEAE and a step-by-step procedure to compute the pedestrian travel-time maps for Alaska coastal communities are provided in Macpherson and others (2017). Note that the data required for the PEAE include: the tsunami hazard zone, assembly areas, digital elevation model (DEM) of the community, and land-cover datasets. In the following subsections we describe the compilation of the datasets required to compute the travel-time maps, the scenarios considered, and the modeling results for Homer.

We visited Homer at the end of 2014 to gain knowledge of the physical setting, collect land-cover data, and collect data necessary to validate the travel-time maps. We investigated several routes and recorded time required to walk them. Details of walked routes and further information gathered on the site visit can be found in Appendix A.

DATA COMPILATION AND SOURCES

The following section details the datasets that were obtained and/or created for the community and used as input for the PEAE. All original datasets were projected to NAD83 Alaska State Plane Zone 10 m to allow us to compute the final evacuation times in meters per second. The original sources of data are summarized in table 1.

- **Tsunami Hazard Zone:** A hazard-zone polygon for PEAE was developed by modifying the inundation limit line for Homer (Suleimani and others, 2005). Because of unaccounted effects of subsidence in the area, and a limited number of tsunami sources, we assume that the entire spit area lies inside the Tsunami Hazard Zone shown in figure 4.
- **Assembly Areas:** Assembly areas were determined by selecting flat areas outside of the hazard zone along major roadways (figure 4). Note that safety zones may be important buildings, places that have been agreed upon by the community as gathering places in times of emergency, or just relatively flat land out of the hazard zone. We assume three assembly areas around the boundary of the tsunami hazard zone: The northern end of the Homer Spit; the Alaska Islands and Ocean Visitor Center, where trails from Bishop's Beach lead; and along Kachemak Road.
- **Digital Elevation Model:** The DEM used in this study is consistent with the tsunami DEM used to compute the tsunami inundation in Homer (Suleimani and others, 2005). The original DEM has a spatial resolution of about 16 × 31 m (52.4 × 101.7 ft). Note that the tsunami DEM was resampled using the PEAE tool to set the analysis cell size at 5 m (16.4 ft) resolution to improve the accuracy of the travel-time maps.
- **Land Cover:** A land-cover layer was created by sampling the 2011 National Land Cover Database (NLCD) for Alaska (Jin and others, 2013). The dataset's land-cover classes were grouped and reclassified based on the standard PEAE land-cover classes. Some editing of the land cover was performed based on high-resolution imagery from GINA BDL WMS (http://www.alaskamapped.org/bdl/) and from knowledge gained during site visits. Next, road and stream data were obtained from the Kenai Peninsula Borough GIS department (http://www.borough.kenai.ak.us/gis-dept). These road and stream shapefiles were edited to include some smaller roads and to create road and stream

polygon features, as the original files were composed of line features. Buildings were digitized from imagery provided in the GINA BDL WMS.

Table 1. Data sources of the input layers required for the Pedestrian Evacuation Analyst Extension.

Layer in PEAE	Data Sources
Tsunami Hazard Zone	Modified from Suleimani and others (2005)
Assembly Areas	Chosen along major routes
DEM	Suleimani and others, 2005
Land Cover	AK NLCD 2011 edited
Buildings	Digitized from GINA BDL WMS
Roads	KPB GIS layer edited
Water	KPB GIS layer edited
Imagery	GINA BDL WMS

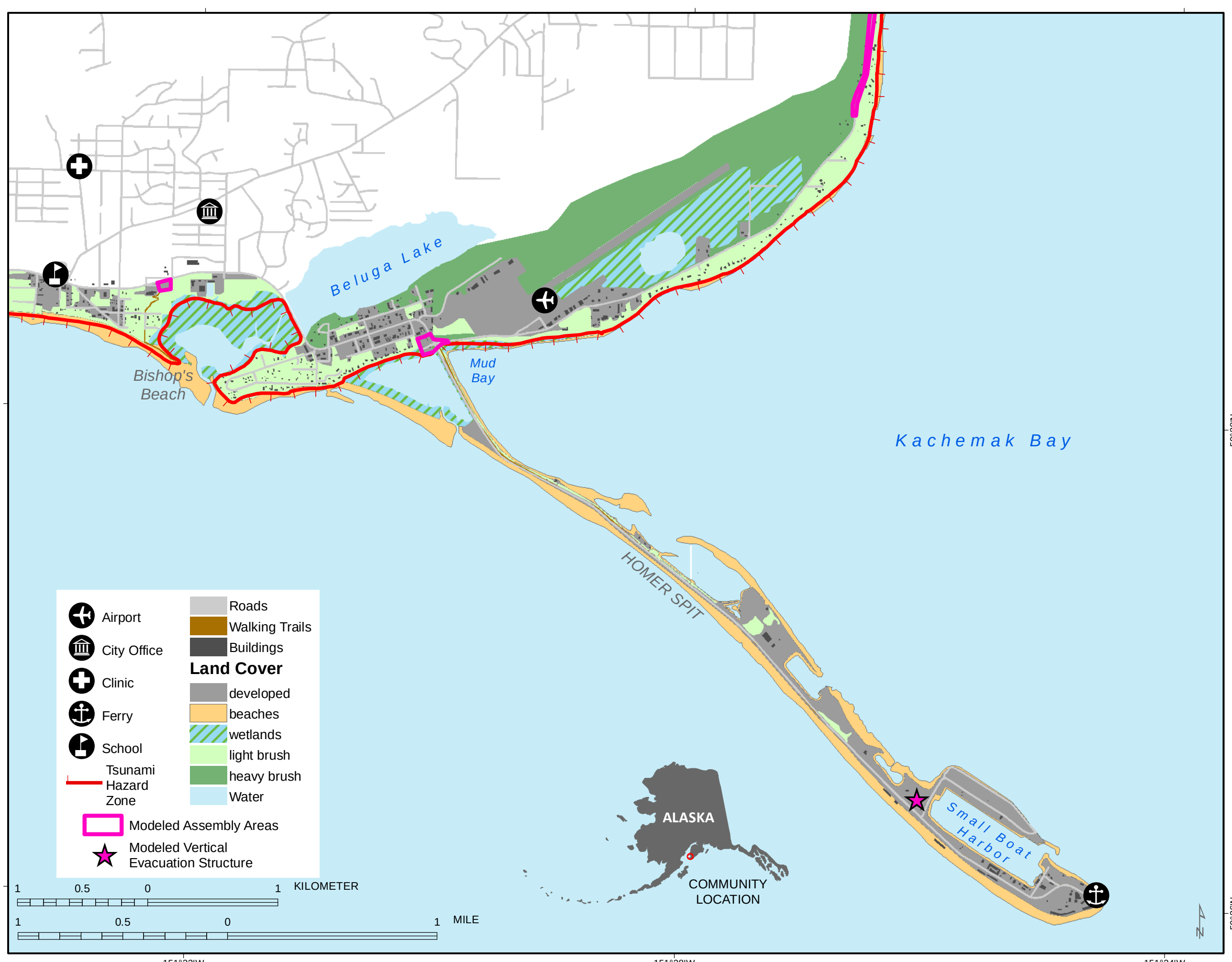


Figure 4. The assumed Tsunami Hazard Zone and modeled assembly area polygons for PEAE.

EVACUATION SCENARIOS

We model the pedestrian evacuation time according to five scenarios (Macpherson and others, 2017). We emphasize that the assumed base speed of the evacuee is set according to the "slow walk" option (0.91 m/s or 3 ft/s) in the PEAE settings. Note that this is a very conservative speed and many residents should be able to evacuate twice as fast (1.52 m/s [5 ft/s] "fast walk", if not 1.79 m/s [5.9 ft/s] "slow run") as the modeled rate.

Scenario 1. **Evacuation to the hazard zone boundary across all terrain**

The pedestrian evacuation from the tsunami hazard zone **over all viable surfaces** to the outer boundary of the hazard zone.

In the case of severe weather conditions or thick snow cover, the evacuation might be confined to well-traveled roads and paths. Therefore, we assume that pedestrians will travel to the closest road and then stay on roads to leave the hazard zone.

Scenario 2. **Evacuation to the hazard zone boundary by roads only**

The pedestrian evacuation from roads and paths in the tsunami hazard zone **along the roads and paths** to the outer boundary of the hazard zone.

In addition to examining pedestrian evacuation to the boundary of the tsunami hazard zone, we consider the following two evacuation scenarios. In both scenarios, we assume that individuals travel to predetermined assembly areas (figure 3), which are chosen on the boundary (or immediately outside) of the tsunami hazard zone on likely evacuation routes. We assume three assembly areas around the boundary of the tsunami hazard zone: The northern end of the Homer Spit; the Alaska Islands and Ocean Visitor Center, where trails from Bishop's Beach lead; and along Kachemak Road.

Scenario 3. **Evacuation to the nearest assembly area across all terrain**

The pedestrian evacuation from the tsunami hazard zone **over all viable surfaces** to the nearest assembly area.

Scenario 4. **Evacuation to the nearest assembly area by roads only**

The pedestrian evacuation from roads and paths in the tsunami hazard zone **along the roads and paths** to the nearest assembly area.

Finally, we consider the effect of a vertical evacuation structure on the pedestrian evacuation from the spit. As discussed earlier, the vertical evacuation structure allows for creation of areas of refuge for communities in which evacuation out of the inundation zone might not be feasible. We model an evacuation structure by placing an additional assembly point near the end of the spit (figure 4).

Scenario 5. **Evacuation to the hazard zone boundary or vertical evacuation structure across all terrain**

The pedestrian evacuation from roads and paths in the tsunami hazard zone **over all viable surfaces** to hazard zone boundary or the vertical evacuation structure.

MODELING RESULTS

We apply the methodology outlined in Macpherson and others (2017) to compute the travel times produced by the five scenarios. The pedestrian travel-time maps are shown on Sheets 1–5, corresponding to Scenarios 1–5.

Scenario 1 reveals that evacuation from any location except the spit could be achieved in less than 20 minutes. It might take up to 160 minutes to travel from the tip of the spit to the boundary of the hazard zone. Such high travel times result from a long travel distance to safety. Recall that the spit is more than 6.5 km (4 mi) in length.

As in the previous scenario, Scenario 2 also predicts high pedestrian evacuation time from the spit. The spit road is readily accessible from any location on the spit, thus we note small differences between the computed evacuation times for Scenarios 1 and 2.

Before discussion of results for Scenarios 3 and 4, we note that one of the potential assembly areas is on the boundary of the tsunami hazard zone right at the base (or beginning) of the spit (figure 4). Because the LCD approach assumes optimal routes, this assembly area determines pedestrian travel times for the individuals at the base of the spit as well as for the entire spit. Hence, the modeling results for Scenarios 3 and 4 resemble results according to Scenarios 1 and 2, respectively. Note that the pedestrian travel time from the tip of the spit is about 160 minutes in all considered scenarios.

The results from Scenarios 1–4 all demonstrate that the estimated evacuation times from the far end of the spit are daunting if one needs to evacuate to the modeled boundary of the tsunami hazard zone. One of the possible solutions is to decrease the distance to safety by constructing a vertical tsunami evacuation shelter on the spit. The modeling results for Scenario 5 show that the travel time to safety could be decreased to only 38 minutes if a vertical tsunami evacuation shelter were available on the spit. In particular, Figure 5 shows a comparison of the travel time to safety with and without of the vertical evacuation site near the harbor.

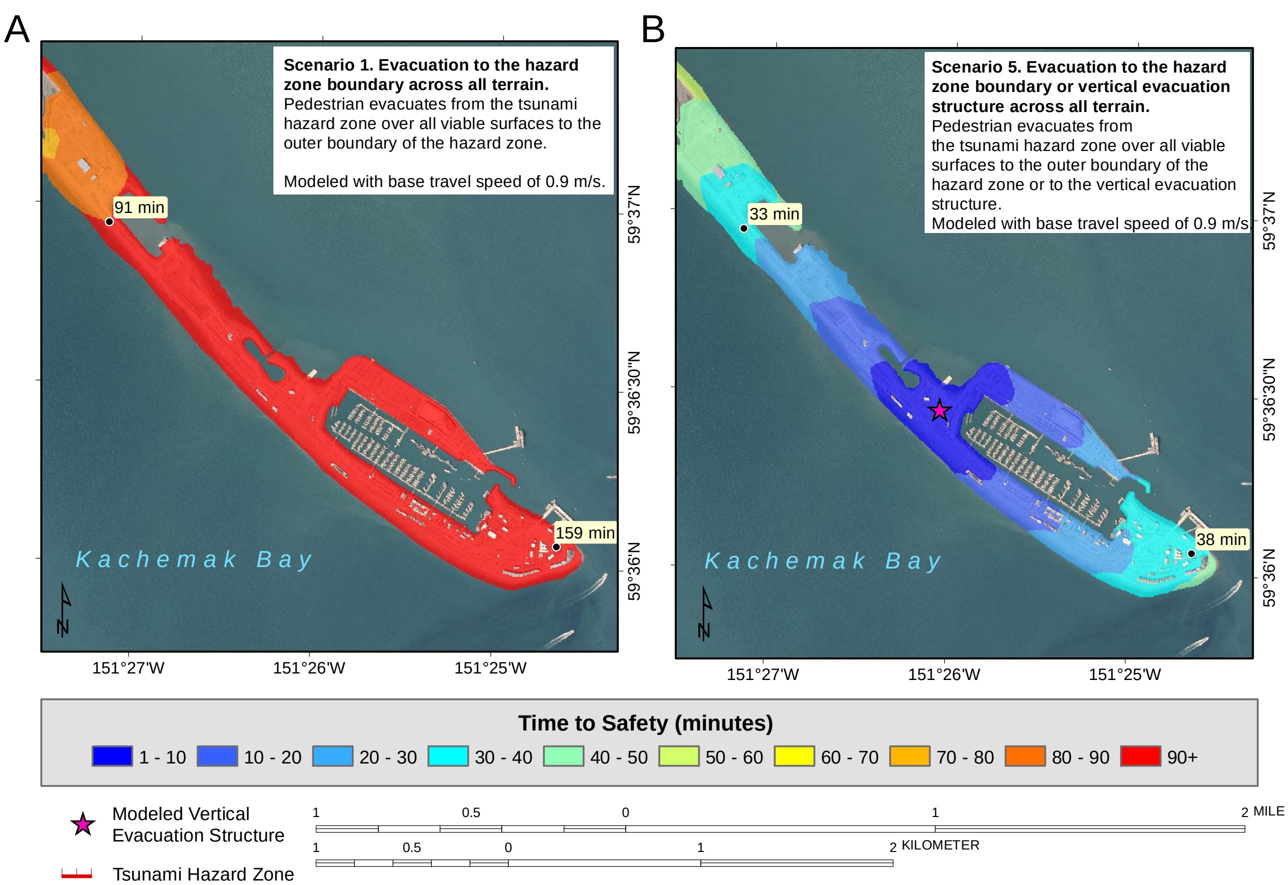


Figure 5. Comparison of the pedestrian travel time to safety without (A) and with (B) a vertical evacuation site near the harbor area.

MODEL VALIDATION

Validation of the results is an important component of each modeling study. We note that Wood and Schmidtlein (2012, 2013) and Jones and others (2014) indicate that modeling results might be sensitive to the spatial resolution of the DEM. Therefore, to ensure that our computations are accurate, we compare numerical calculations for Scenario 2 with site visit data (walking and timing the various routes confined to roads). While it is not feasible to walk every potential route to safety it is a good test to ensure that the model is producing reasonable times for pedestrian evacuation over the most likely paths to safety.

In this report, we investigate an evacuation route from the Homer spit (figure 6). To compare the *in situ* measured walking times to the modeled results, the measured walking times must be adjusted to account for the differences between the *in situ* walking speed and the modeled walking speed of 0.91 m/s (3 ft/s). We first note that it took about 98.13 minutes to walk 7,001 m (22,969 ft) along Track 1. Thus, an average *in situ* walking speed along Track 1 is about 1.189 m/s (3.9 ft/s). Therefore, if the same route had been traveled at a slower speed of 0.91m/s (3 ft/s), then the travel time would be $98.13 \times 1.189 \div 0.91 \approx 128.2$ minutes. The *in situ* measured walking time, average speed, and adjusted travel times are listed in Table 2. The modeling results according to Scenario 2 (evacuation by roads to the hazard zone boundary) indicate that it takes about 150 minutes to cover the same route. While there is a somewhat large discrepancy between the two times (15 percent greater modeled time) this could be from the inability to perfectly match the modeled route to the walked route or possible inaccuracies in field GPS collection; or perhaps it shows some weakness in the model for travel over longer distances—7 km (4.35 mi) in this case.

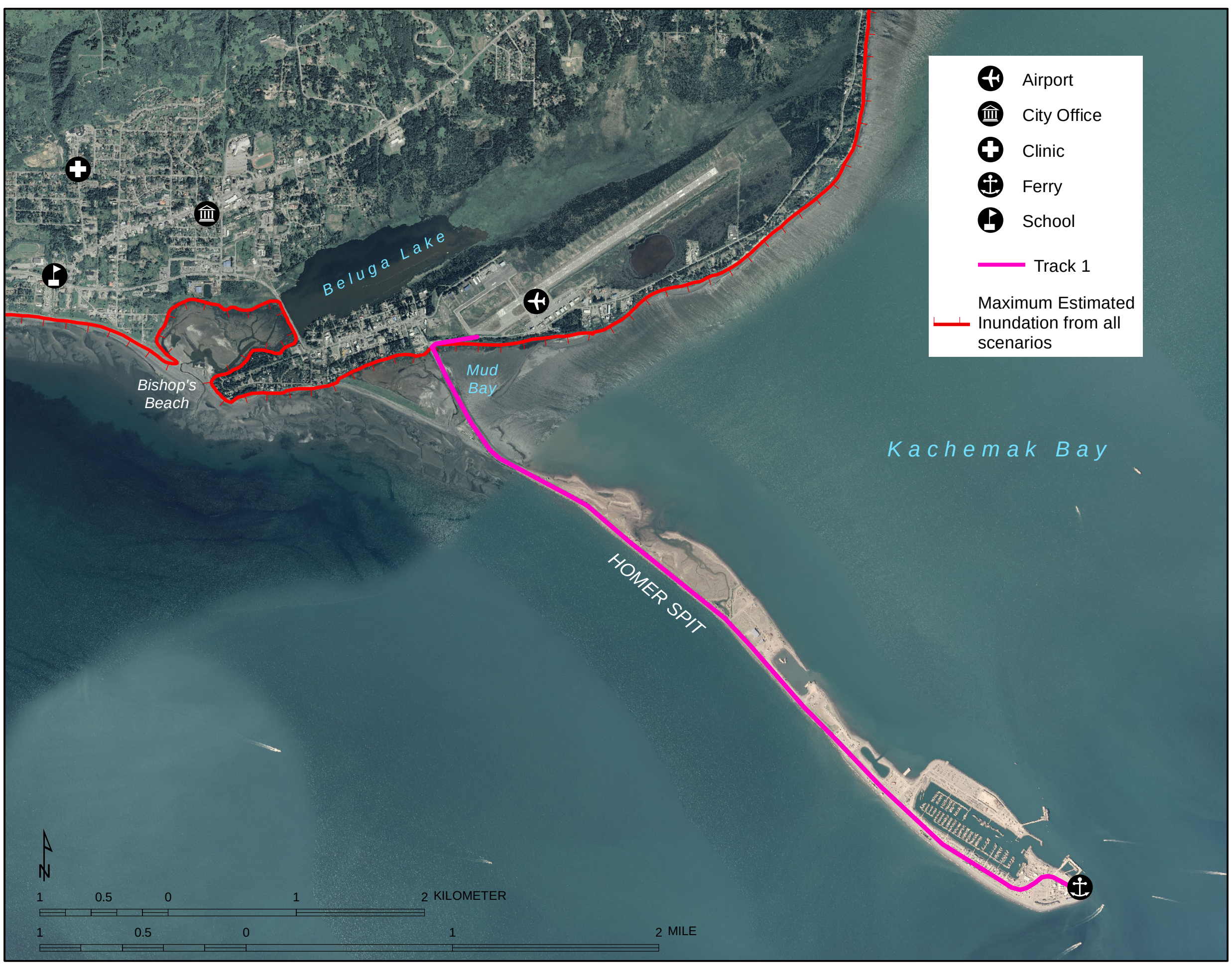


Figure 6. Tracks from site visit used to validate evacuation model times.

Table 2. Measured and modeled travel time along two routes in the tsunami hazard zone.

Track	*In situ* measured walking time (minutes)	Walked distance (meters)	Average walking speed (m/s)	Modeled time (minutes)	Recalculated *in situ* walking time (minutes)
1	98.13	7,001	1.189	150	128

SOURCES OF ERRORS AND UNCERTAINTIES

The modeling approach described in this report will not exactly represent an actual evacuation; like all evacuation models, the LCD approach cannot fully capture all aspects of individual behavior and mobility (Wood and Schmidtlein, 2012). The weather conditions, severe shaking, soil liquefaction, infrastructure collapse, downed electrical wires, and the interaction of individuals during the evacuation will all influence evacuee movement. We employ a "slow walk" travel speed of 0.91 m/s (3 ft/s). Refer to Wood and Schmidtlein (2012, 2013), Jones and others (2014), and Macpherson and others (2017) for an in-depth discussion of the limitations of the LCD approach in estimating the travel times to safety.

SUMMARY

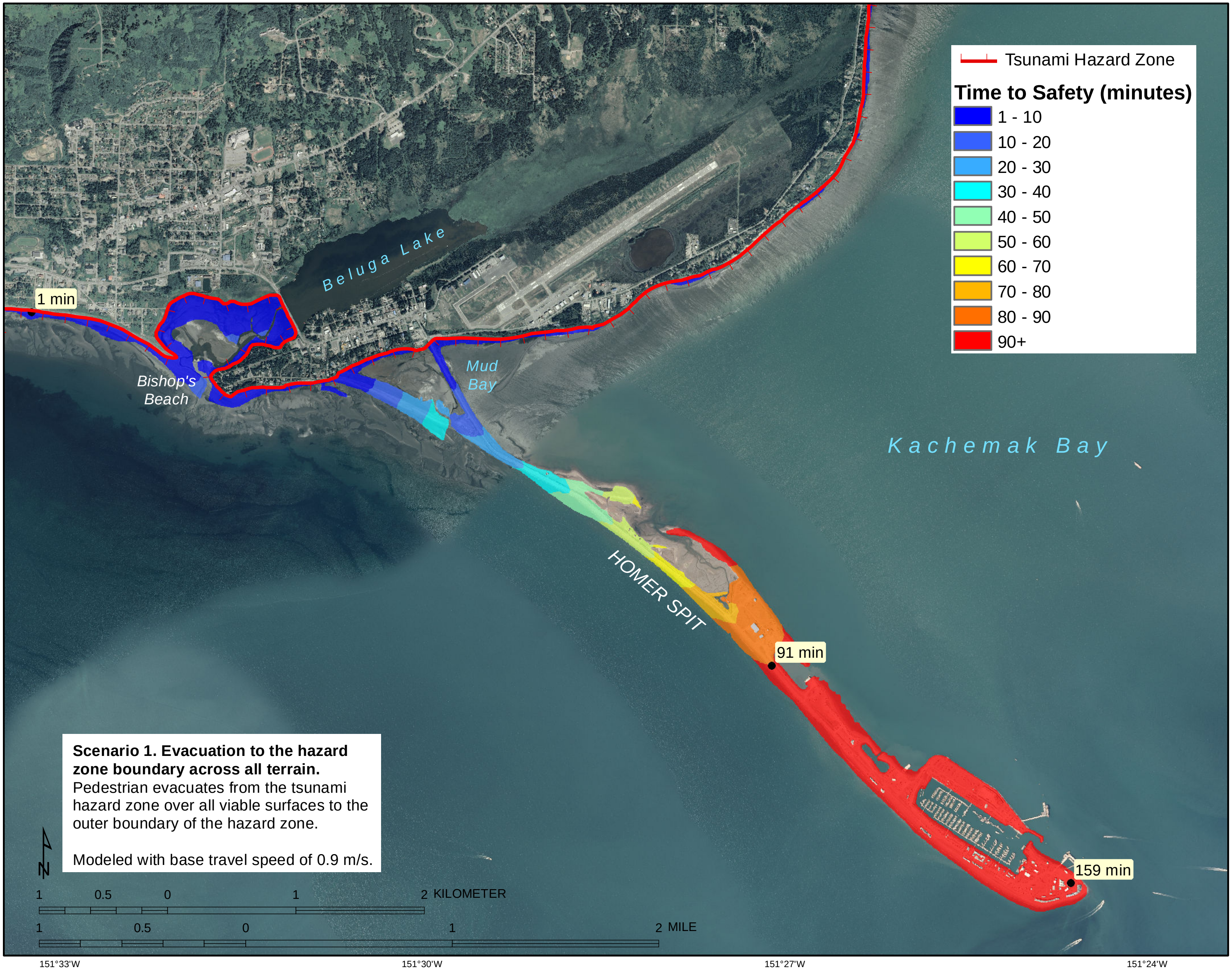
Maps accompanying this report have been prepared using the best information available and are believed to be accurate; however, their preparation required many assumptions. Overall, times generated by the model seem reasonable when compared to actual walking time. Development of the vertical evacuation structure on the spit can drastically decrease pedestrian travel time to a place of refuge. The pedestrian travel times should be used only as a guideline for emergency planning and response action. Some individuals less familiar with the area might take a less optimal route and consequently require more time to reach safety. Additionally, in case of emergency some individuals might require some time to recognize an imminent tsunami danger, which could delay their evacuation. The information on this map is intended to assist state and local agencies in planning emergency evacuation and tsunami response actions. These results are not intended for land-use regulation or building-code development.

ACKNOWLEDGMENTS

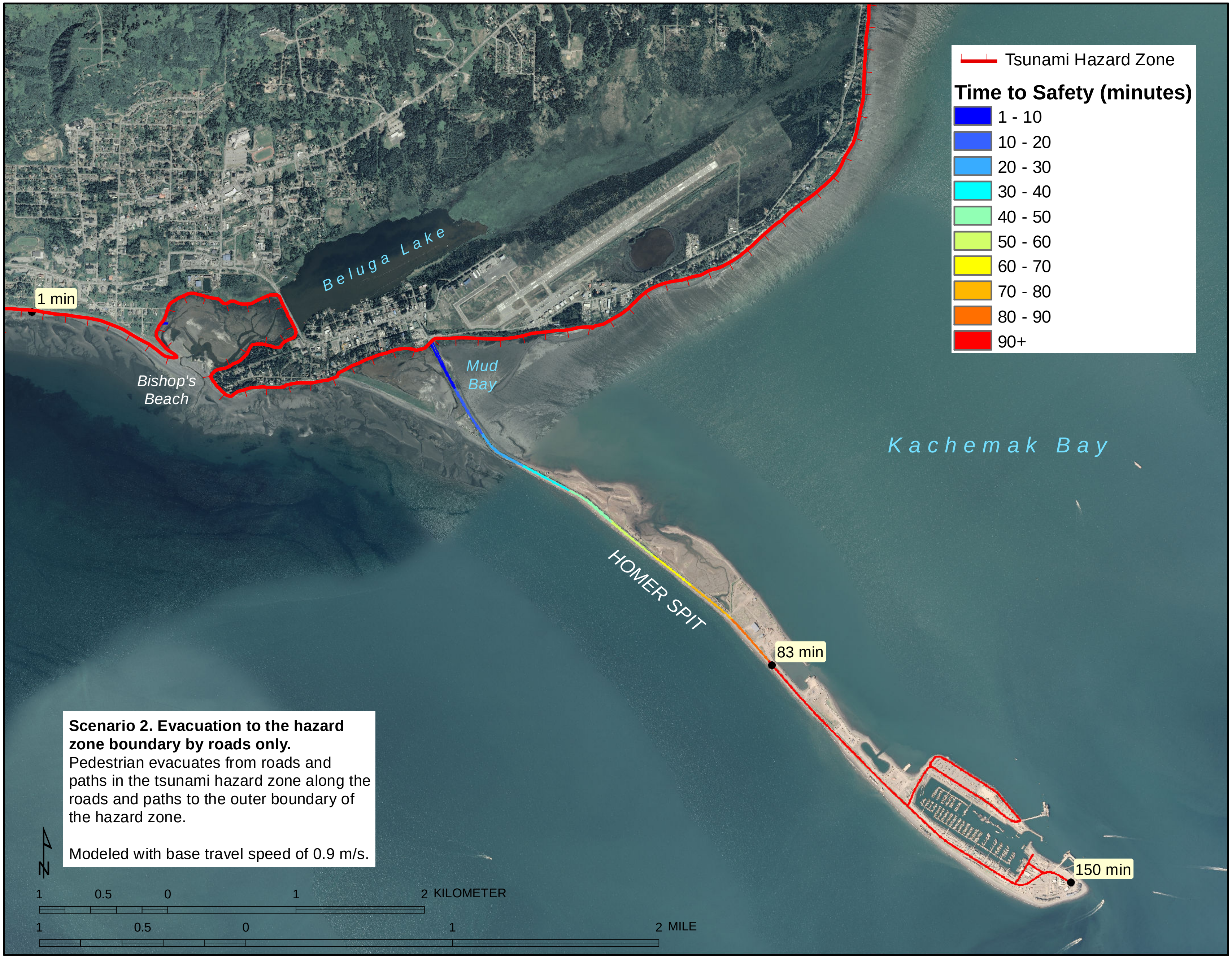
Local knowledge was invaluable to this project and the members of the community were eager to discuss their plans and thoughts. This project received support from the National Oceanic and Atmospheric Administration (NOAA) under Reimbursable Service Agreements ADN 952011 with the State of Alaska's Division of Homeland Security and Emergency Management (a division of the Department of Military and Veterans Affairs). A thoughtful review by Nathan Wood (USGS) improved the report and maps.

APPENDICES

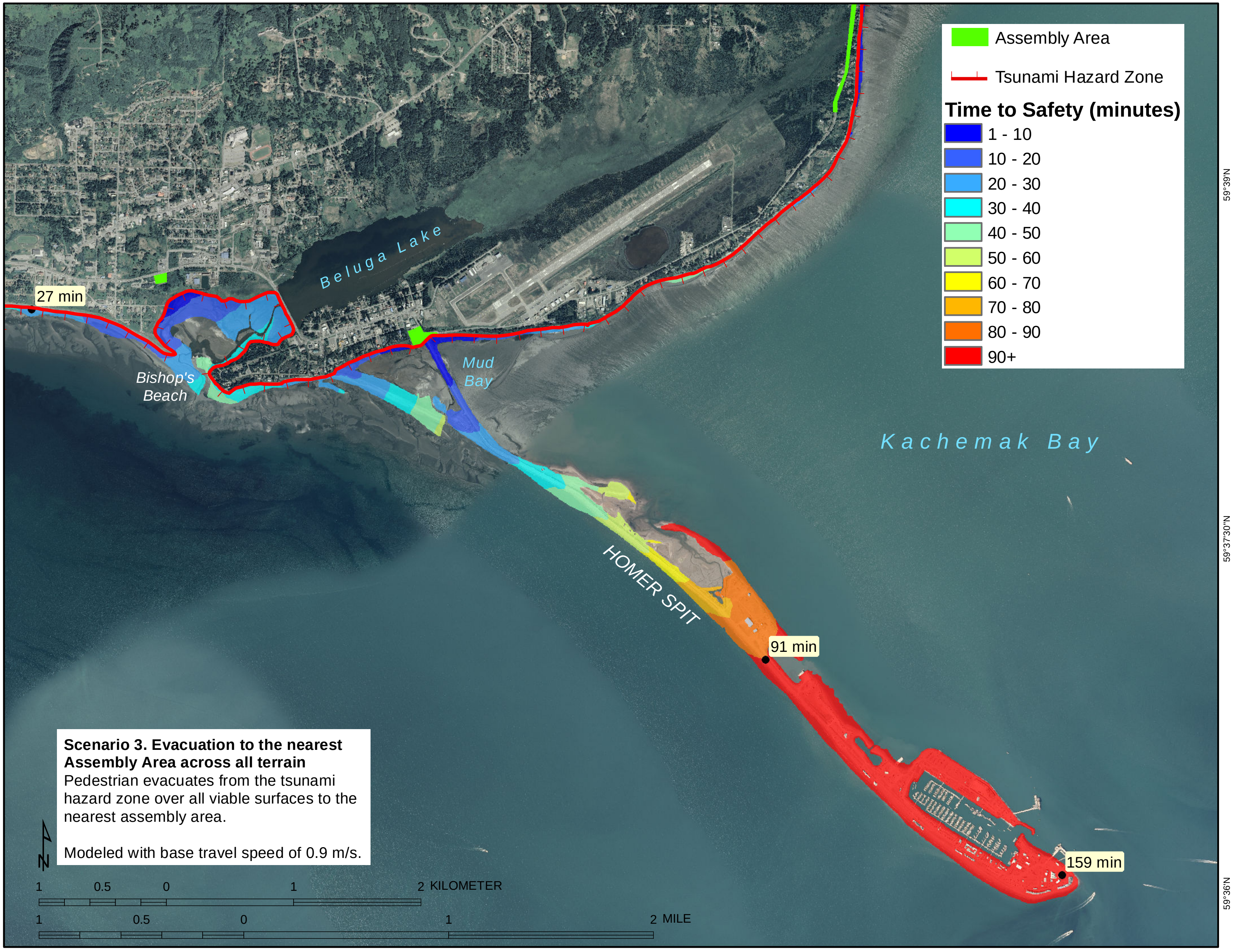
APPENDIX A: Site Visit Report for Homer, Alaska



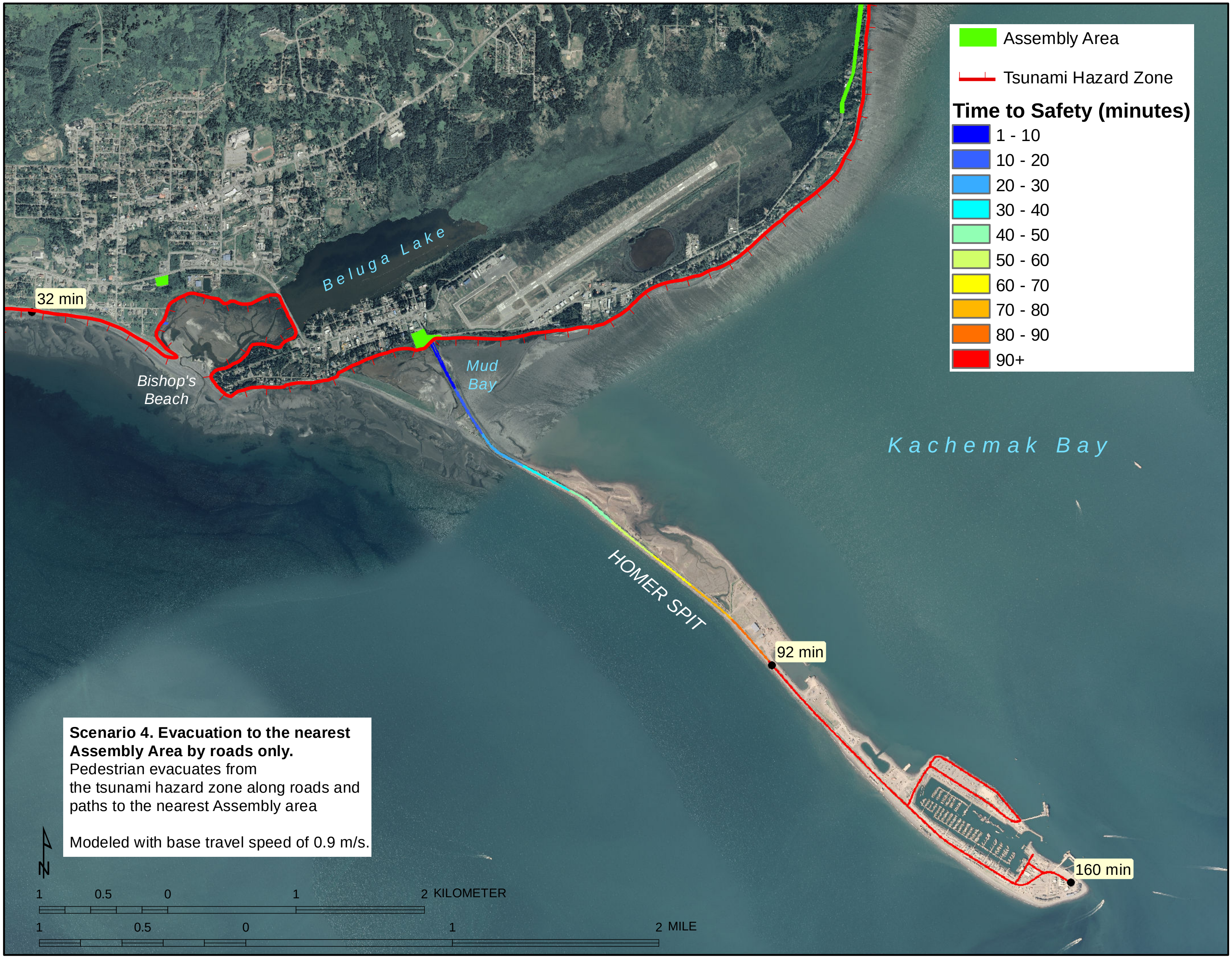
MAP SHEET 1: Travel-time map of the pedestrian evacuation to the hazard zone boundary across all terrain



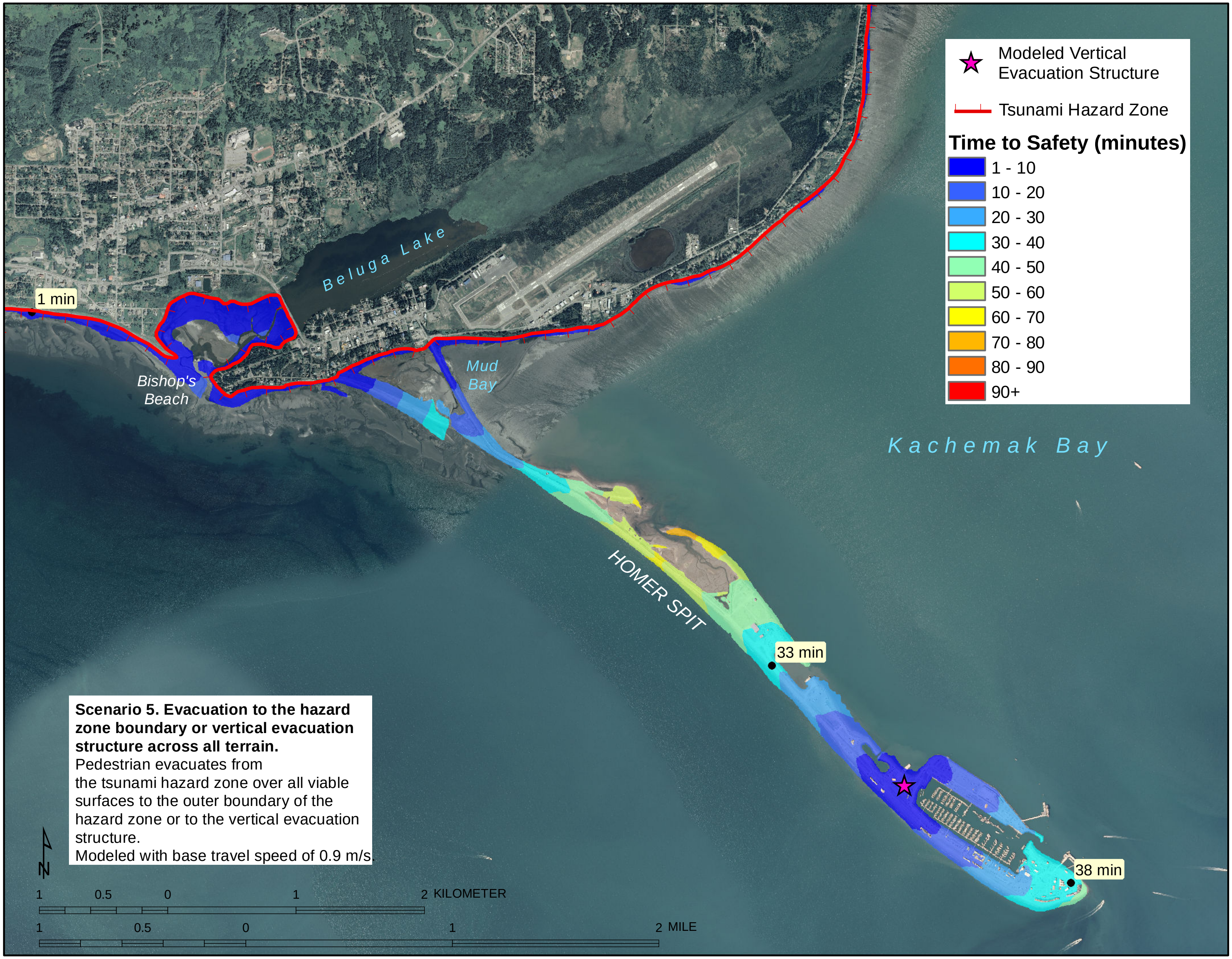
MAP SHEET 2: Travel-time map of the pedestrian evacuation to the hazard zone boundary by roads only



MAP SHEET 3: Travel-time map of the pedestrian evacuation to assembly areas across all terrain



MAP SHEET 4: Travel-time map of the pedestrian evacuation to assembly areas by roads only



MAP SHEET 5: Travel-time map of the pedestrian evacuation to the hazard zone boundary and a vertical evacuation structure across all terrain

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